New Features in Pythia (v6.420)

- New Tunes to LEP data → Better Fragmentation Models
- New Tunes to Tevatron data → Better Underlying-Event Models
  Combined → New "Professor" and "Perugia" Tunes

Outlook to Pythia 8

Thanks to N. Moggi, R. Field, A. Buckley, H. Hoeth
Basic aim: improve lowest order perturbation theory by including leading corrections \(\rightarrow\) exclusive event samples

1. sequential resonance decays
2. bremsstrahlung
3. underlying event
4. hadronization
5. hadron (and \(\tau\)) decays

Even the most sophisticated calculations currently only scratch the first few orders of couplings, logs, powers, twists, \(\ldots\) \(\rightarrow\) “tuning” needed. Realistic assessment of uncertainties non-trivial.
Why Study the “Underlying Event”? 

► Solving QCD requires Compromise
  • Pythia alone contains many different models, + Herwig, + Sherpa …

► Fragmentation / Hadronization
  • Hadronization can only be studied “in isolation” at LEP
    ▪ Normal procedure: constrain fragmentation models at LEP and cross fingers
    ▪ = EXTRAPOLATION
  • What about in situ constraints on fragmentation!?
    ▪ Important to verify pion spectra, etc, directly in the experiment
    ▪ At least for min-bias / UE, but ideally for processes as close as possible to signal

► Feedback to high-pT physics
  • Reliable correction procedures
  • Without reliable models, reliable extrapolations are hard to hope for

Experimental input vital to guide construction of theory

Peter Skands
From the Tevatron to LHC - 3
Classic Example: Number of tracks

UA5 @ 540 GeV, single pp, charged multiplicity in minimum-bias events

Simple physics models ~ Poisson
Can ‘tune’ to get average right, but much too small fluctuations
→ inadequate physics model

More Physics:
Multiple interactions + impact-parameter dependence

Moral (will return to the models later):

1) It is not possible to ‘tune’ anything better than the underlying physics model allows

2) Failure of a physically motivated model usually points to more physics (interesting)
Starting point: matrix element + parton shower

- hard parton-parton scattering
  - (normally 2→2 in MC)
- + bremsstrahlung associated with it
  - 2→n in (improved) LL approximation

But hadrons are not elementary
+ QCD diverges at low $p_T$
→ multiple perturbative parton-parton collisions
  e.g. 4→4, 3→3, 3→2

No factorization theorem
→ Herwig++, Pythia, Sherpa: MPI models
particle production

\[ Q_F \gg \Lambda_{QCD} \]

\[ \text{ME+ISR/FSR} \]

+ perturbative MPI

\[ Q_F \sim \Lambda_{QCD} \]

- Hadronization
- Remnants from the incoming beams
- Additional (non-perturbative / collective) phenomena?
  - Bose-Einstein Correlations
  - Non-perturbative gluon exchanges / color reconnections?
  - String-string interactions / collective multi-string effects?
  - “Plasma” effects?
  - Interactions with “background” vacuum, remnants, or active medium?

Need-to-know issues for IR sensitive quantities (e.g., \( N_{ch} \))
Many nomenclatures being used.

- Not without ambiguity. I use:

\[ Q_{\text{cut}} \]

Primary Interaction

\(~\text{trigger}\)
mpi create kinks
on existing strings, rather than new strings

<table>
<thead>
<tr>
<th>MPI Models in Pythia 6.4</th>
</tr>
</thead>
</table>

- **Old Model: Pythia 6.2 and Pythia 6.4**
  - “Hard Interaction” + **virtuality-ordered** ISR + FSR
  - $p_T$-ordered MPI **without** ISR/FSR
  - Momentum and color explicitly conserved
  - Color connections: $\text{PARP}(85:86) \rightarrow 1$ in Rick Field’s Tunes
  - No explicit color reconnections

- **New Model: Pythia 6.4 and Pythia 8**
  - “Hard Interaction” + **$p_T$-ordered** ISR + FSR
  - $p_T$-ordered MPI + **$p_T$-ordered** ISR + FSR
    - ISR and FSR have **dipole kinematics**
    - “**Interleaved**” with evolution of hard interaction in one common sequence
  - Momentum, color, and **flavor** explicitly conserved
  - Color connections: random or ordered
  - Toy Model of Color reconnections: **“color annealing”**

Hard System + MPI allowed to undergo color reconnections
October 2008: Perugia Workshop

- Huge model building and tuning efforts by many groups (Herwig, Professor, Pythia, Sherpa, ...)

From Pythia Side:

- LEP data revisited → better fragmentation tunes
- More Tevatron data included → better underlying-event tunes
- LEP + Tevatron tunes combined: new generation of tunes
  - Both old-fashioned tuning (Rick Field, me) but now also first set of tunes using fully automated approach ("Professor")
  - Updated tunes available for BOTH new and old MPI models!
  - + Systematic HARD / SOFT / CR / PDF variations (incl LO*)
- All included in Pythia 6.4.20, available via PYTUNE
  - See 6.4.20 Update Notes for full documentation
The New Tunes

► Old Framework

• Tune 103: Rick Field’s “old” best Tevatron tune: “DW”

• Tune 113: “DW-Pro”
  ▪ Revamped to include Professor tuning of fragmentation parameters.
  ▪ Useful to estimate how big difference is between old and new fragmentation tuning

• Tune 129: “Pro-Q2O” Professor tune of Q2-ordered showers and old MPI model
  ▪ Currently recommended “best” tune of old model.
  ▪ Includes Professor’s LEP and Tevatron 630-1800-1960 tunes.

► New Framework

• Tune 320: “Perugia 0” tune of pT-ordered showers and new MPI
  ▪ Currently recommended “best” tune of new model
  ▪ Includes both LEP and Tevatron 630-1800-1960 data (+ some UA5 data)
  ▪ + also includes Tune 321 – 326: HARD / SOFT / PDF / etc variations

• Tune 329: “Pro-pTO” Professor tune of pT-ordered model
  ▪ Alternative to Perugia 0 obtained with fully automated tuning
Jet Fragmentation : LEP

- Improvements in descriptions of LEP spectra
  - E.g., momentum spectra and particle multiplicities

https://users.hepforge.org/~holsch/wiki/tune_flavour/comparisonplots.html
In addition to the improved LEP parameters, more sophisticated tunes have been done to the Tevatron data

- Including also data at 630 GeV → energy scaling better constrained

http://home.fnal.gov/~skands/leshouches-plots/
Aspen Predictions:

- $|\eta| < 2.5$
- $p_T > 0.5 \text{ GeV}$
- $\langle N_{\text{tracks}} \rangle = 13.5 \pm 1.5$

- $1.8 < \eta < 4.9$
- $p_T > 0.5 \text{ GeV}$
- $\langle N_{\text{tracks}} \rangle = 6.5 \pm 1.0$
Conclusions

► Substantial Recent Revisions
  • Updated flavour and fragmentation parameters (LEP)
  • To see effects on you, compare “Tune X” with “Tune X-Pro”
    ▪ For this purpose, “-Pro” versions of all previous tunes included with 6.4.20
    ▪ E.g., compare “DW” with “DW-Pro” (old), or “S0A” with “S0A-Pro” (new)
  • Useful to check your sensitivity to these changes

► Improved hadron collider tunes
  • Including improved constraints on energy scaling to LHC
    ▪ Important to check spectra in-situ to best extent possible ( + please publish! )
  • For serious productions: now recommending “Perugia” or “Professor” tunes (+ systematic variations → first attempt at uncertainty bands)
    ▪ No further substantial updates are foreseen in near future

► Enter Pythia 8
  • Professor Team now working on full-fledged tune of Pythia 8
    ▪ As well as Herwig++, Sherpa